15 Apr 2004, 7:00pm - 8:30pm

Soil Improvement Using Deep Dynamic Compaction

Omar M. Alsamman
Langan Engineering and Environmental Services, Elmwood Park, New Jersey

George P. Kelley
Langan Engineering and Environmental Services, Elmwood Park, New Jersey

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

SOIL IMPROVEMENT USING DEEP DYNAMIC COMPACTION

Omar M. Alsamman, Ph.D., P.E.
Langan Engineering and Environmental Services
Elmwood Park, NJ (USA)

George, P. Kelley, P.E.
Langan Engineering and Environmental Services
Elmwood Park, NJ (USA)

ABSTRACT

The use of a conventional shallow foundation system in the construction of a baseball stadium on the Delaware River waterfront was only possible by improvement of existing soils using deep dynamic compaction (DDC). Subsurface conditions at the site consisted of 5 ft to 15 ft of miscellaneous fill materials overlying up to 10 ft of soft river sediments over dense sand. Numerous obstructions and old foundations were found in the fill making pile driving difficult and extremely expensive. Several foundation designs and ground improvement alternatives were evaluated for building support. A deep dynamic compaction soil improvement plan was designed to allow for the use of a conventional shallow foundation and slab-on-grade system.

Prior to construction, a full-scale plate load test was performed at a dynamically compacted area to verify soil behavior under maximum column loads. The load test was monitored using precise survey methods to determine settlements as well as using piezometers to monitor pore water pressure changes due to the DDC impacts. Soil borings were also drilled to verify soil improvement. Analysis of the load test and boring results showed that the soil improvement using DDC was effective and would allow the use of a shallow foundation system to support the stadium's loads. The use of deep dynamic compaction proved to be an economical alternative resulting in significant savings in construction cost and a shorter construction schedule.

HISTORICAL BACKGROUND

The project site is situated on the Delaware River waterfront in Camden, New Jersey, across from the downtown Philadelphia skyline. Prior to the mid 1800's, the site was formerly a marshland or even below river water. During the industrialization of the waterfront in the early 1900's, the soft river muds were filled over and large pile-supported buildings with heavily reinforced foundations were constructed.

As the industrial activities declined in the 1970's, buildings became abandoned and were demolished but the poor soils and old massive foundation remnants remained as challenges to be dealt with by future projects. Historically, the redevelopment of the Camden Waterfront was thwarted not only by market conditions and inadequate infrastructure but also by difficult subsurface conditions, which significantly increased the cost of building construction. However, at present, there are many new projects in the waterfront area and the baseball stadium with the crowds that it draws serves as an anchor for the entire area.

PROPOSED CONSTRUCTION

The project consisted of building a 6,425-seat minor league baseball stadium consisting of a 3-story cast-in-place concrete structure with the associated clubhouse, picnic areas, scoreboards, light stands, and other site structures. Typical column loads were between 100 kips and 300 kips, with some larger column loads of up to 650 kips. Typical column spacing was 32 ft x 20 ft and wall loads were in the order of 10 kips/ft. The ground level of the planned stadium corresponded approximately to existing site grades.

SUBSURFACE CONDITIONS

The initial subsurface investigation program consisted of drilling 28 borings and excavating 8 test pits. Eight additional borings were drilled to supplement initial data. The subsurface conditions generally consist of 5 ft to 15 ft of miscellaneous fill materials overlying 2 ft to 10 ft of silt with varying organic content. These deposits are underlain by a thick alluvial deposit consisting of sand with some silty gravel layers and occasional silty clay layers. The fill included various buried foundations and demolition debris. Groundwater was encountered in the test pits between 6 ft and 8 ft below the ground surface. Due to the proximity of the site to the Delaware River, the groundwater level was somewhat influenced by tide levels.

EVALUATION OF FOUNDATION ALTERNATIVES

Several foundation systems and soil improvement schemes were evaluated. The most cost-effective and practical approach was based on improving the existing soils in place rather than removal and replacement of large amounts of unsuitable soils, or the use of pile foundations, which would be very difficult and cost-prohibitive. The soil improvement program included utilizing deep dynamic compaction in combination with conventional vibratory surface compaction for stadium columns and slab areas, and surcharging for other site elements when this process would not interfere with project schedule.

DDC PROGRAM

The DDC program was designed to allow for the use of a conventional shallow foundation system with an allowable bearing pressure on the improved soils of 2 tons per square foot. Dynamic compaction was performed at the stadium columns, slab areas, and wall footings using a 13-ton weight dropped from a height of 65 feet. The number of overlapping drop locations at each column varied between 4 and 9 locations, depending on the size of the column footing. The number of drops at each drop location was 5 drops for columns with loads up to 160 kips and 7 drops for column loads over 160 kips. In the slab areas and wall footings, the weight was dropped over a 10-ft grid using 5 drops at each drop location.

Due to the close proximity of drop locations to each other at a given column, the drops were made in 2 to 4 passes to allow for pore water dissipation. The minimum time allowed between passes was determined to be 3 days based on the piezometer readings performed at the plate load test.

FULL-SCALE PLATE LOAD TEST

Prior to the start of the DDC program, a full-scale plate load test was conducted to verify soil behavior under the maximum column loads after a test area was compacted using the selected DDC procedure. The area of the site with the thickest compressible soils and no known buried foundations was selected as the test area. This type of testing was performed to provide direct verification of soil improvement rather than relying only on indirect methods such as confirmation borings. The test was performed at a dynamically compacted area and monitored using precise survey methods to determine settlements as well as using piezometers to monitor pore water pressure changes due to the dynamic compaction impacts.

The test was set up by first excavating to a depth of 3 ft below the ground surface, placing an 8-ft-long by 8-ft-wide by 8-inch-thick steel plate at the bottom of the excavation, and then stacking weights on the plate sufficient to produce a 2 ton/ft^2 stress on the soil. Approximately 140 tons of cast-iron blocks were transported from a location over 100 miles away and stacked to a height of about 12 ft. Zero elevation readings were taken on the bottom plate prior to placement of the weights. Elevation readings were measured at the reference points immediately after the maximum load was reached and, subsequently, on every other day or after weekends. The monitoring results are plotted in Fig. 1.

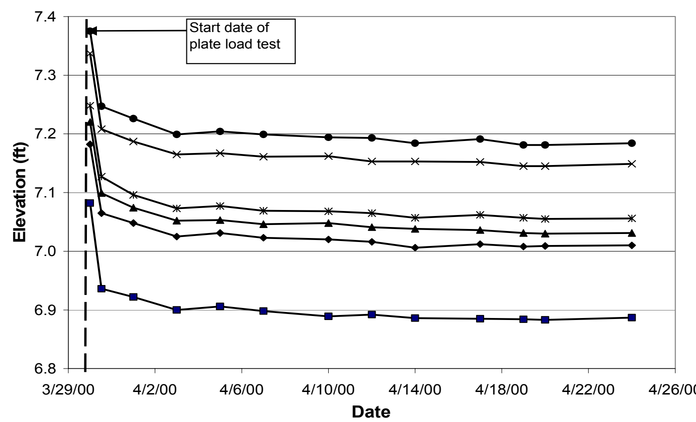

Fig. 1. Settlement measurements for 6 monitoring points at the plate load test.

The monitoring results show that a settlement of about 1.5 inches occurred immediately after the placement of the maximum test load. Subsequently, there was approximately an additional 0.5 inch of settlement that occurred over a period of 4 days. Settlement readings showed little change, thereafter, and amounted to less than 0.25 inch in the remaining 16 days of monitoring.

In addition to the elevation survey conducted at the plate load test, two other methods were used to monitor and verify dynamic compaction effects on soil behavior. This included drilling a soil boring at the test area and installing piezometers around the test area to monitor pore water pressure changes prior to and during the test. The information obtained from these investigations is summarized below.

Confirmation Boring

One boring was drilled at the center of the test area and showed that a significant amount of mixing had occurred between the fill and the deeper silty soils. Additionally, N-values in the boring increased considerably from the pre-compaction values in nearby borings.

Piezometers Data

Three piezometers were installed around the test area in the silty soil layer to monitor the change in pore water pressure prior to and during the load test. The monitored piezometer readings are plotted in Fig. 2. Readings made 2 days after dynamic compaction indicated pore water pressures that were about 0.7 psi to 1.9 psi higher than the baseline pressure due to the groundwater table.

The monitored pore water pressure continued to decrease until the morning of the load test, when piezometer readings had fallen close to the baseline pressure. As the maximum load was applied at the test area, a 1.0 to 1.2 psi jump was noticed in the piezometer readings. The majority of the load-test-induced pore water pressure had essentially dissipated within two days, as can be seen in Fig. 2. This tends to indicate that the lower cohesive soils have been significantly mixed with the upper fill and their permeability characteristics have significantly increased.

Load Test Results Interpretation

The initial 1.5 inch movement observed immediately after placing the full load is primarily due to "seating" of the heavily loaded steel plate on the underlying fill material. We believe that the majority of this initial settlement would not have occurred had the test area been proofrolled with a heavy vibratory roller, as was to be accomplished prior to the foundation construction. The 0.5 inch of settlement observed over the first 4-day period and the additional 0.25 inch of movement were likely due to the slower compression of the deeper soil layers that are within the zone of influence of the footing. It was judged that such movement measured at the highest column load would be tolerable for the proposed structure.

OTHER CONFIRMATION BORINGS

During the initial stages of DDC production work and to verify the effects of the dynamic compaction in areas where buried thick slabs or foundations were present, several borings

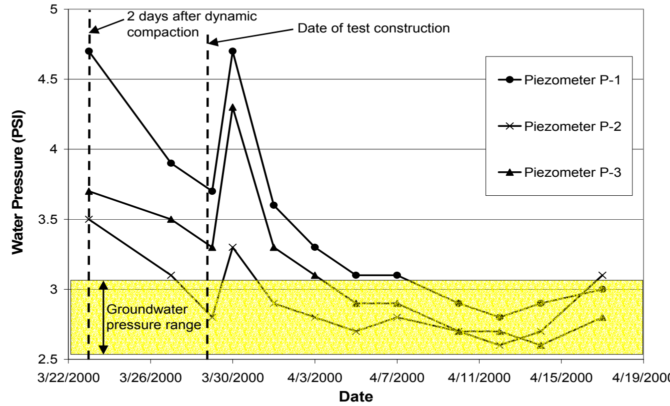

Fig. 2. Plot of piezometer readings at the plate load test area versus time.

were drilled after DDC treatment was completed. The borings indicated that below these foundation elements, the silt layer was essentially unaltered by the compaction work. This confirms that no deep compaction or mixing was accomplished in these areas. This is apparently because the dynamic compaction weight did not penetrate the foundation elements, even when the drop energy was increased. The work progressed in these areas by excavating and exposing these elements, breaking them into smaller pieces using pneumatic hammers, and re-compacting these areas again in order to achieve the required soil improvement. The DDC pounder was utilized as a tool to detect buried foundations, when shallow craters were observed. It was also sometimes used to crush and compact foundation remnants.

A few borings were also performed in other DDC-treated areas and these showed a significant increase in N-values from the pre-compaction values as well as considerable mixing between the fill and the underlying silt.

OBSERVATIONS AND CONCLUSIONS

1. The full-scale instrumented plate load test provided direct verification of the effectiveness of soil improvement technique and provided invaluable information on soil behavior after DDC impacts.

2. Field observations indicated that crater depths of 3 ft to 6 ft were formed with little noticeable heave. The crater depth decreased with each pass.

3. The DDC provided an invaluable tool to detect, crush-in-place, and compact old foundation remnants at the site.

4. The soil improvement program allowed for the use of a conventional shallow foundation system and slab-on-grade resulting in significant cost savings and shorter construction schedule.

5. The stadium was completed on May 2000 and no unacceptable settlements have been noted.

ACKNOWLEDGEMENT

The authors would like to thank their firm, Langan Engineering and Environmental Services, Inc. (the geotechnical, site-civil, roadway, landscaping, and surveying consultant), and the client, Cooper's Ferry Development Association/ The Quaker Group for the opportunity to work and present this case history. Successful completion of this project and meeting the project's tight schedule was a team effort. The success of the project depended on the skills, commitment, and experience of all the personnel involved. The specialty contractor who performed the work was The Dynamic Compaction Company, Inc. Other key consultants are the Construction Manager, Quaker Construction Management, Inc., the Architect, Clarke Caton Hintz, and the structural engineer, Harrison-Hamnett, P.C.

REFERENCES

Menard, L. and Broise, Y. [1975]. "Theoretical and Practical Aspects of Dynamic Consolidation", Geotechnique, London, England, Vol. 25, No. 1, pp. 3-18.

Leonard, G.A., et. Al. [1980]. "Dynamic Compaction of Granular Soils", Journal of The Geotechnical Engineering Division, Proceedings of the ASCE, Vol. 106, No. GT1, January.

Lukas R.G. [1986]. "Dynamic Compaction for Highway Construction. Volume 1: Design and Construction Guidelines", Federal Highway Administration Report FHWA/RD-86/133.